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# Towards Scalable Protocols:
# From Thermodynamics to Infodynamics

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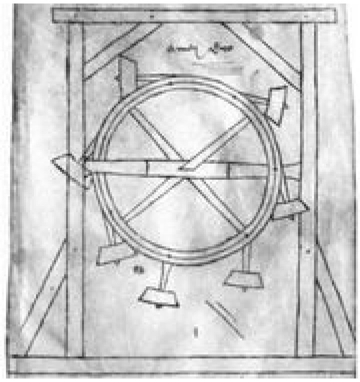
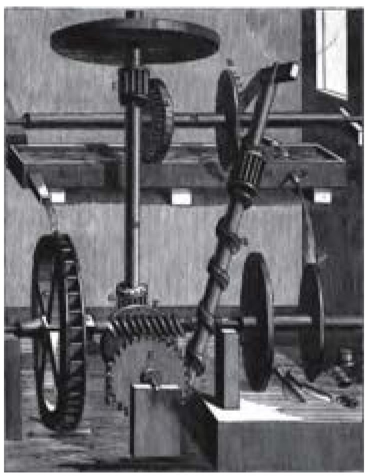
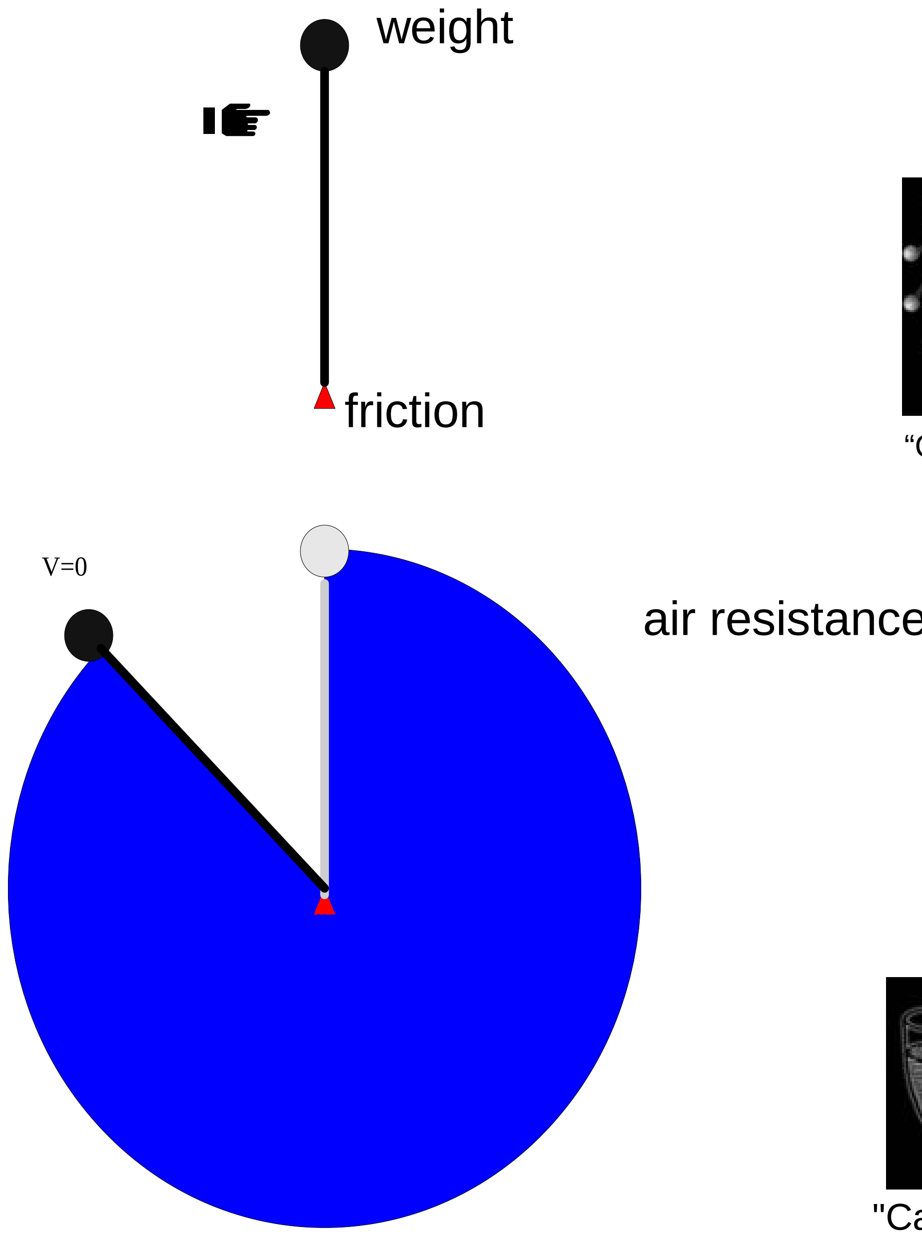
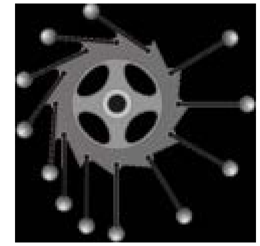


"Villard de Honnecourt", around year 1230

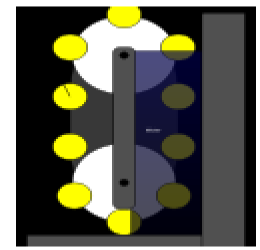


Actual system, "water screw" 1618

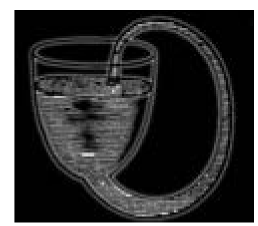


"Overbalanced Wheel"



"Float Belt"



"Capillary Bowl"

# The quest for a *Perpetual Motion* Machine

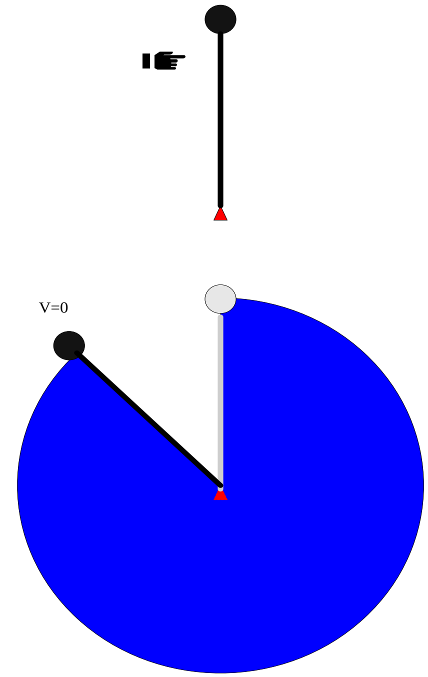
# (before mid 19$^{th}$ century)

# The outcome: The three laws of thermodynamics

- Research on efficient machines tries to design a \`perpetual-motion' machine that runs continuously off its own exhaust.

- Mid 19th century: the three laws of thermodynamics.

- Which also proved that it is impossible to design such a machine!



# From Thermodynamics to ‘Infodynamics’— the Cost of Knowledge in Dynamic Networks

- The first law of thermodynamics can be interpreted as “you cannot get something from nothing, because matter and energy are conserved .” [C.P. Snow]

- So if a protocol that forwards data around needs to know some information about how to forward it, how much work (overhead) does the protocol need to exert?

- Considering a variable topology network, such as for example a mobile ad hoc network; It is a dynamic system in a certain state.

- So, with Laws of Infodynamics, we may:
  - Characterize variability (or uncertainty) of the network state of interest
  - Relate it to the minimum protocol information needed to maintain knowledge
  - Discover some basic limits on protocol effort a.k.a overhead

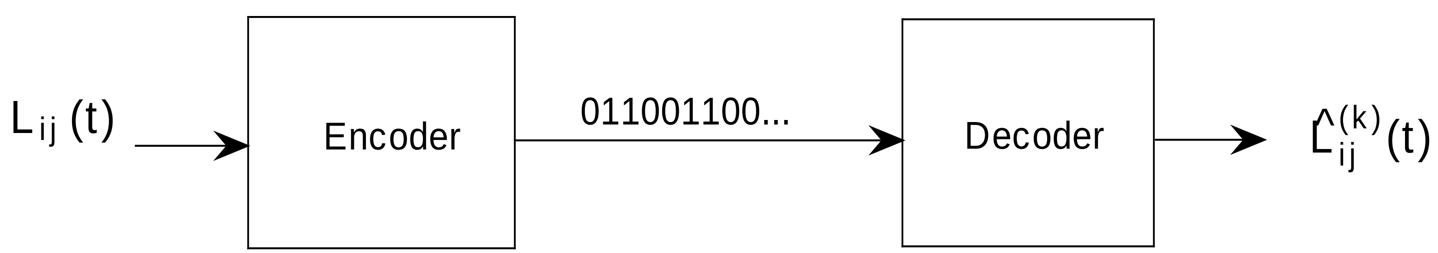
- In the process, we will learn:
  - Fundamental deep results about how to design protocols for scalability
  - Reference curves defining the feasibility and performance (similar to Shannon’s Capacity for error free communication)

# Distorsion Bounds on Protocol Information

- State accuracy affects performance
  - e.g. in geographic routing, if error in distance information is less than the communication radius, protocol performance will not suffer significantly
- Always exists a distortion between actual and perceived state.
  - Due to delays, packet loss, and other network aspects.
- In practice, can live with some distortion e.g. GPS driving directions are accurate within a few meters.
- Thus, interested in the knowledge subject to a specified distortion bound between actual and perceived states.
- Gives rise to a rate distortion problem
- This approach is applicable to any dynamic network:
  - Topology based networks (state = link)
  - Location based networks (state = location)
  - Generic state (e.g. state = available bandwidth, channel state, …etc.)

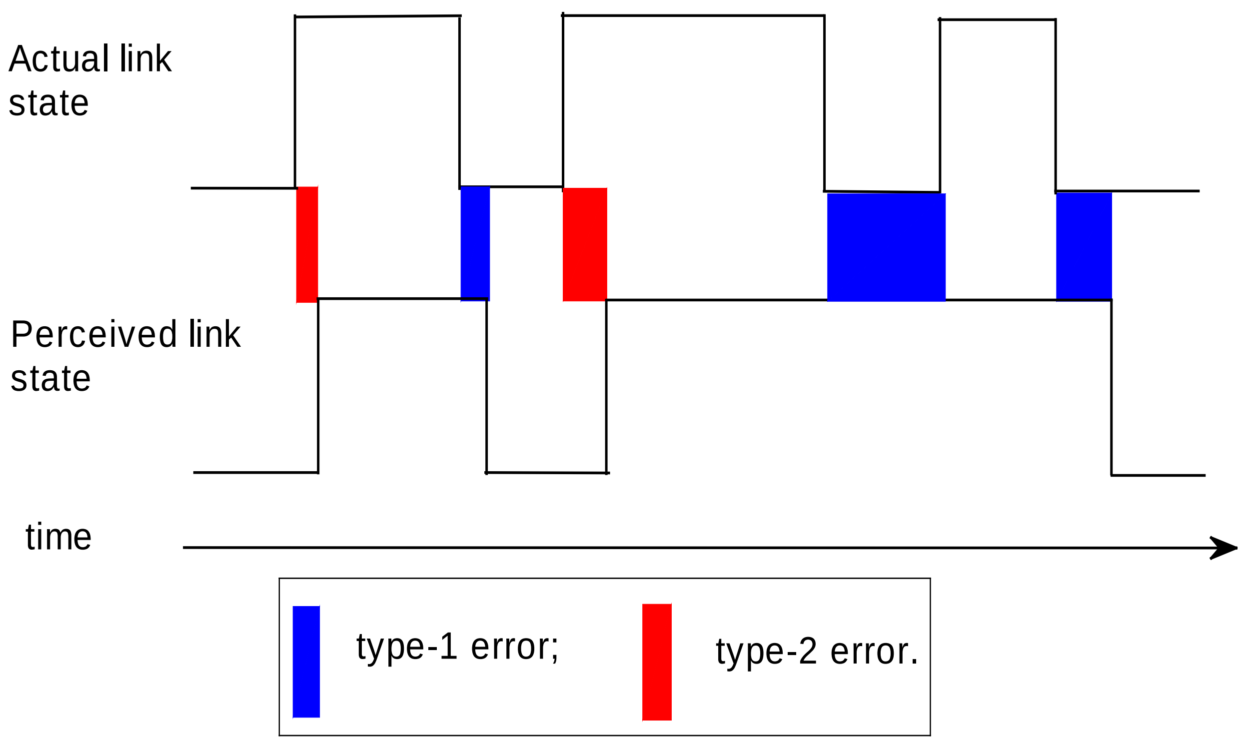
# Modeling

- Link State Routing Protocol Model
  - A node *k* collects link state (or location) information from other nodes such that it can compute a path to any potential destination nodes.
  - The link state information of any given node pair *(i,j)*, *(i≠j)*, may be encoded and sent out, and then received and decoded by node *k* in order to allow *k* to monitor the link status of *(i,j)*.
  - *(i,j)'s* actual link status at time *t*: $L_{ij}(t)$
  - The perceived link status (by *k*) at time *t*: $\hat{L}_{ij}^{(k)}(t)$



# Problem Formulation

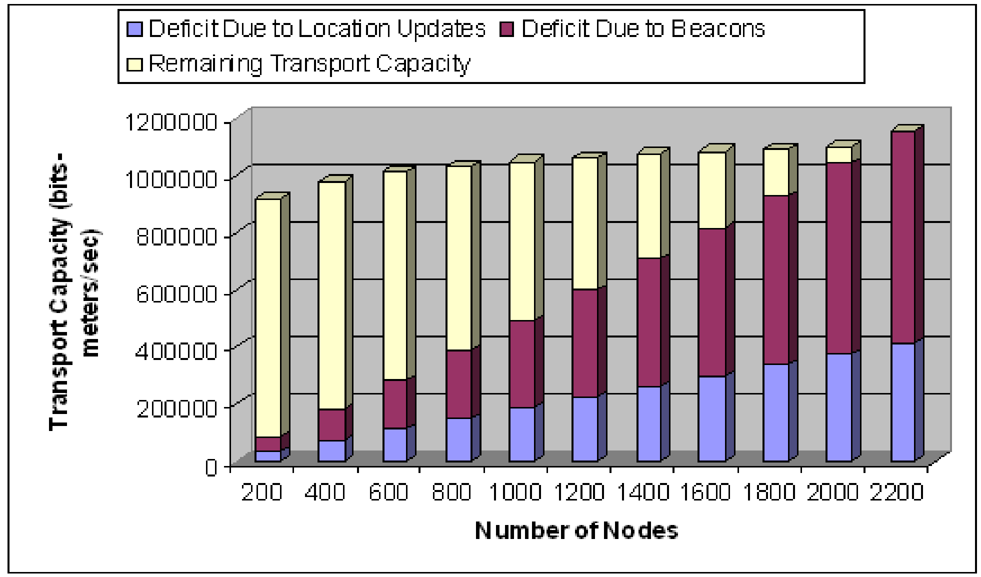
- There are two types of error in link state information
  - Type-1: the link is ‘down’ but is perceived as ‘up’;
  - Type-2: the link is ‘up’ but is perceived as ‘down’.
- Design for minimum update rate subject to error bound

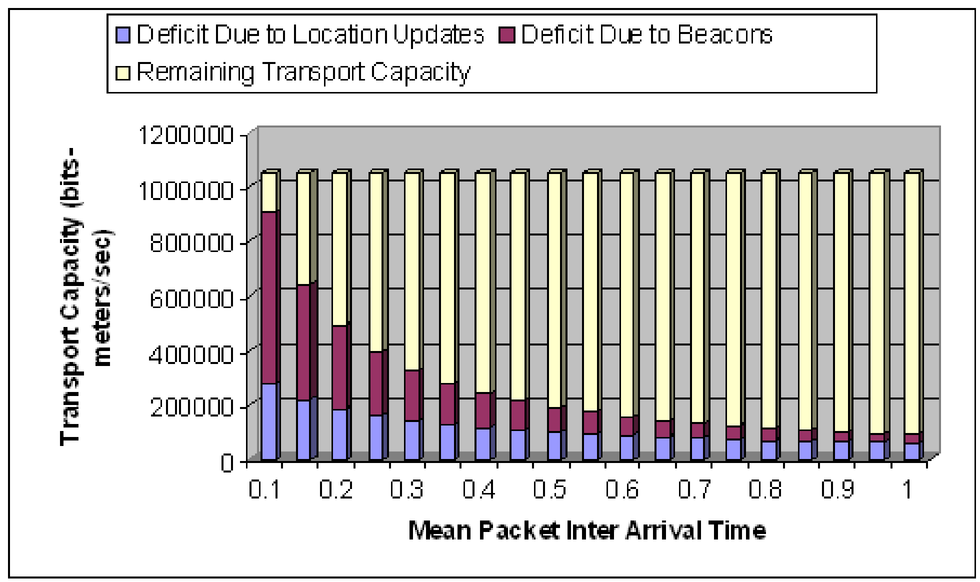


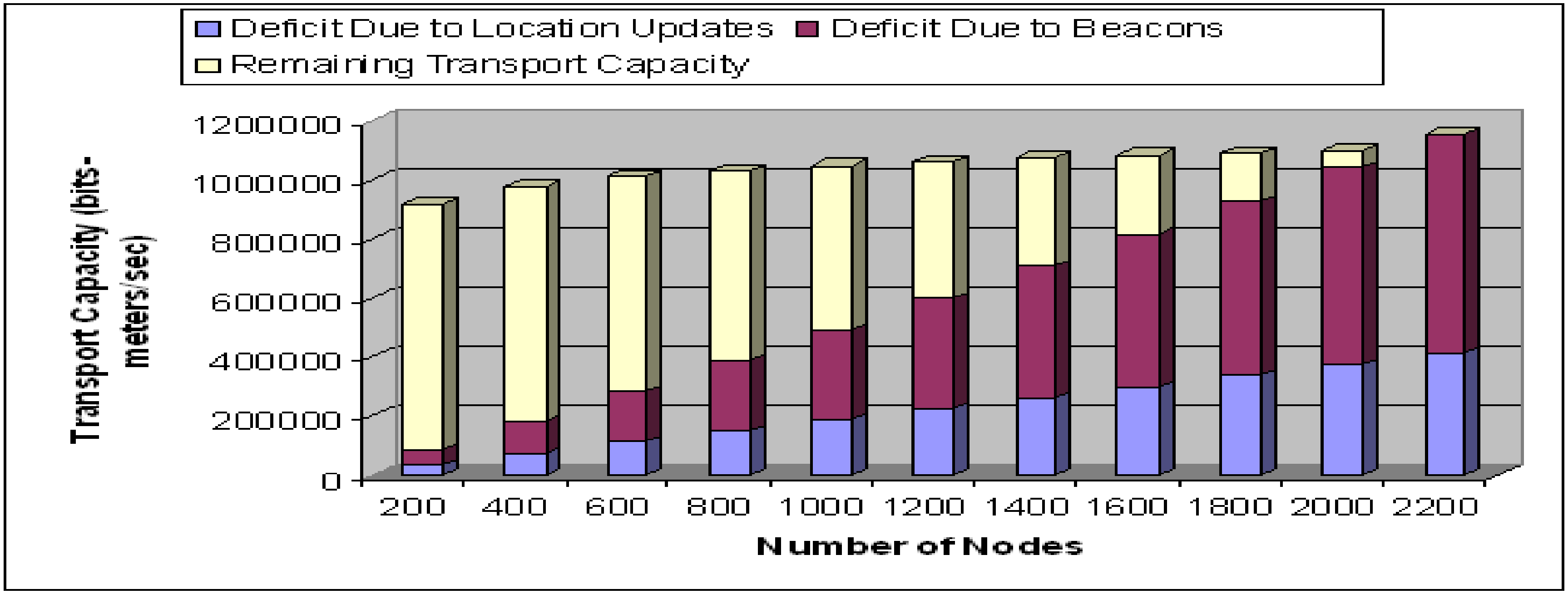
# Application: Geographic Protocols Overheads

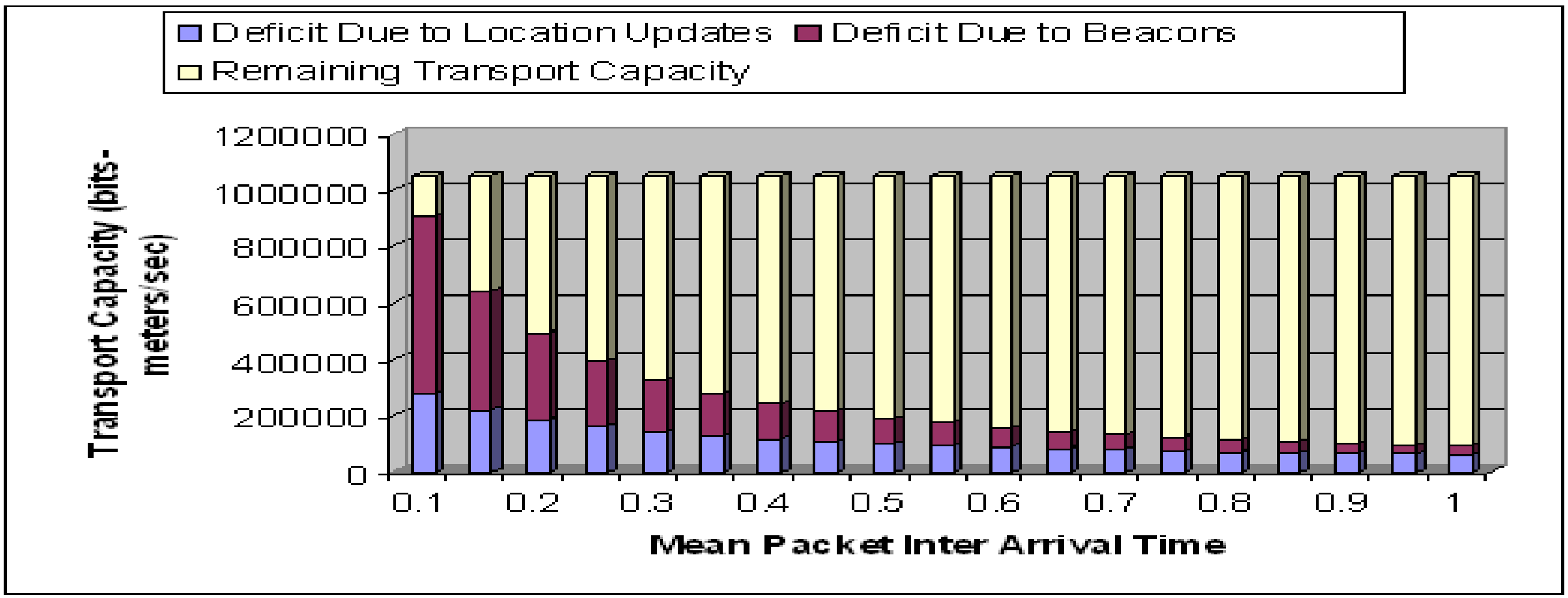
## *Capacity Deficit*

- Routing overheads lead to deficit in the effective capacity available to network users
- Characterizing the deficit is important for understanding the true scaling laws of wireless networks
- Combining information theory and mobility modeling, we characterize the minimum deficit in the transport capacity caused by geographic routing overheads [IT11]
- The deficit is highly sensitive to packet arrival rate and number of nodes
- If network size or packet arrival rate is above certain threshold then complete capacity is used up by protocol information
- Application to link-state in [TMC12,IT09]



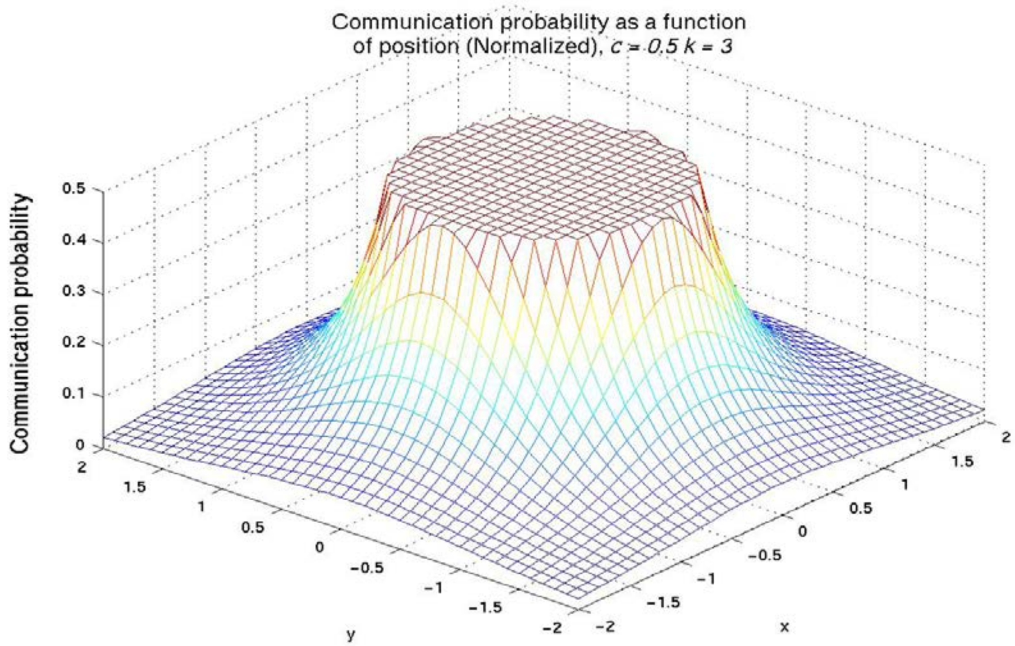






Nodes on a Torus conducting Brownian motion [IT11].

# Infinitely Scalable Protocols (e.g. Reactive Routing) in Dynamic Networks




- Discovered certain S-D patterns for which the reactive routing overhead scales with n as O(1): *infinitely* scalable conditions. The results hold for many types of connected networks [JSAC05]
  - Intuition: if long paths are needed only rarely, then the network will seem clustered "on the average"
- these concepts also used for injecting state that has "weak semantics" that scale better [ToN10,WiNet13].

# Summary

- Can not get something from nothing: Need to discover the rules that govern protocol information scaling in ad-hoc networks, and utilize them in designing for scale.

# References

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